Homogeneous EM Calorimeter R&D for EIC

(part of eRD1)

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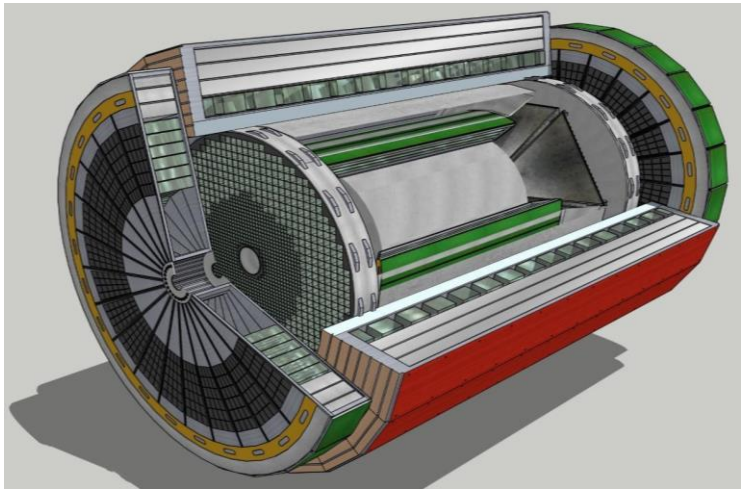
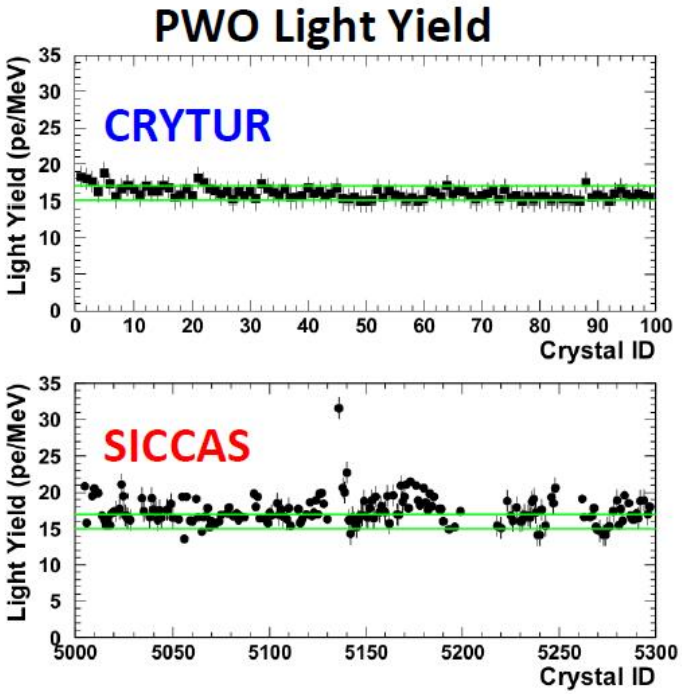
Outline

- $PbWO_4$ crystals for high resolution e-endcap EM calorimeter (R&D largely completed)
- SciGlass for cost effective high resolution EM calorimeter (short-term – about 1 year – R&D needed)
- SCGlass for potential improvement of hadron calorimetry (medium-term – about 3 years – R&D needed)



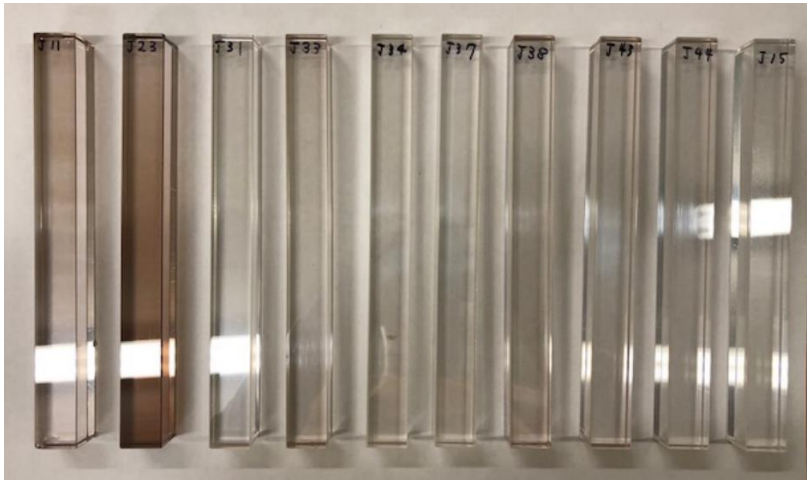
$PbWO_4$ (PWO) crystals: manufacturers

- Up to 2010 – PWO-II production at BTCP, Russia
  - Missing funding -> bankruptcy of BTCO
- Limited availability of reliable SICCAS (China) crystals that would be compatible with experiment requirements
  - ~900 produced for JLab projects since 2017 – Q&A concerns, 30-40% rejection
- 2014 – restart of high-quality PWO-II production at CRYTUR, Czech Republic
  - ~900 produced for JLab projects since 2018 at rate of ~20-30 crystals /month
- Cost of PWO crystals ($15-25/cm^3)

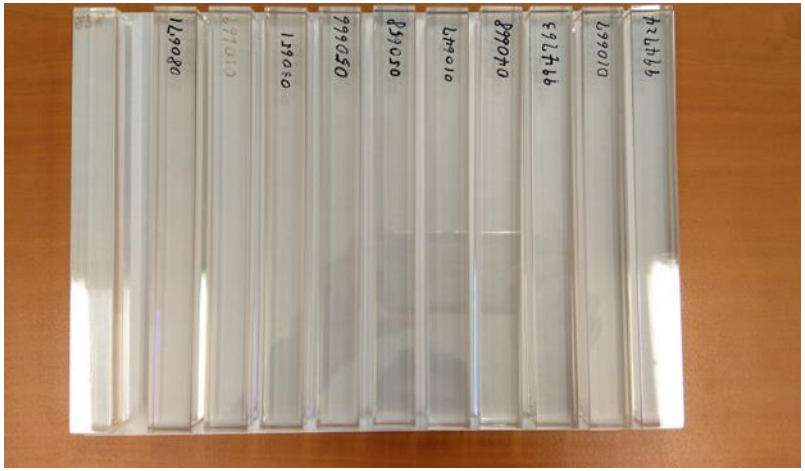


PWO: radiation hardness

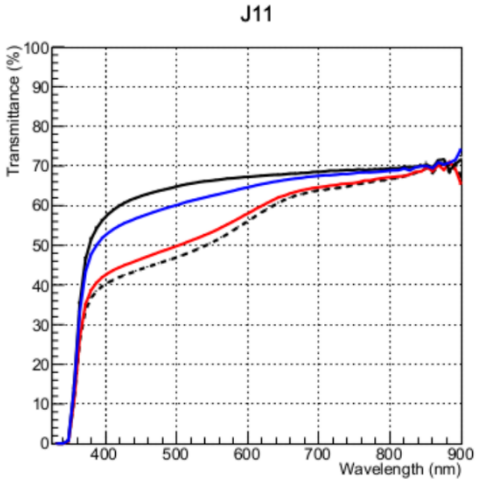
^{60}Co source irradiation

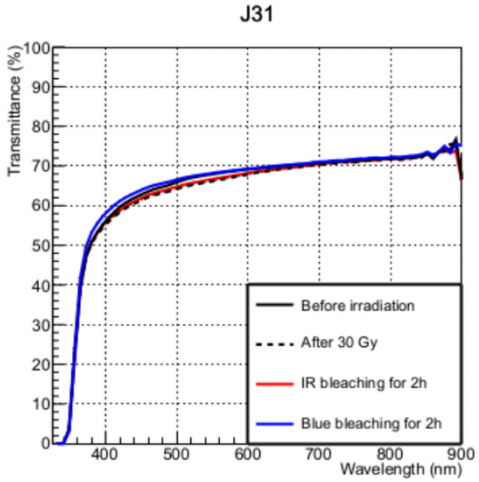


SICASS: 0.5 MRad



Crytur: 1 MRad





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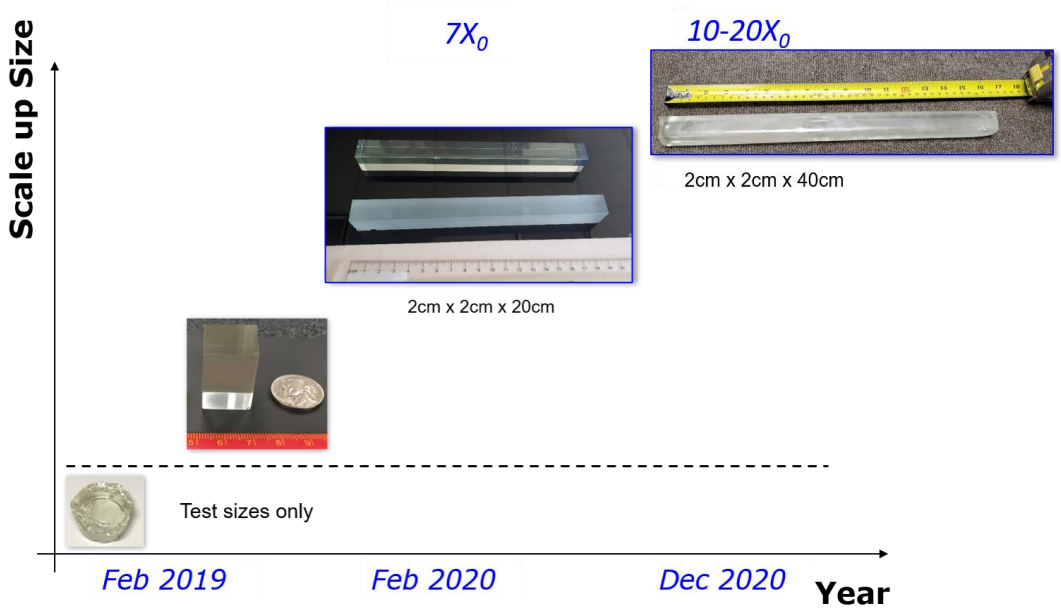
Glass Scintillator - SciGlass

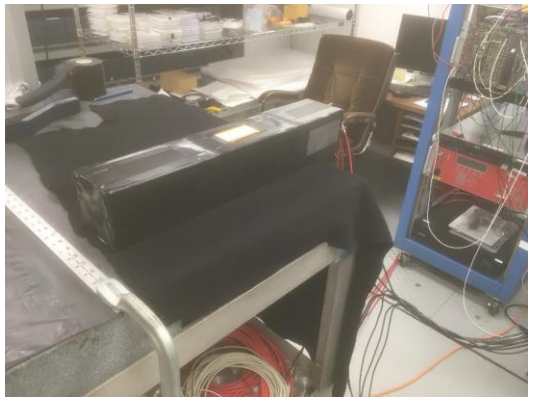
SCINTILEX

- SciGlass is a radiation hard material optimized to provide characteristics similar to or better than PbWO4.
  - Fabrication is expected to be cheaper, faster, and more flexible than PbWO4 crystals.
- SciGlass is being developed by Scintilex, LLC in collaboration with the Vitreous State Laboratory at CUA.



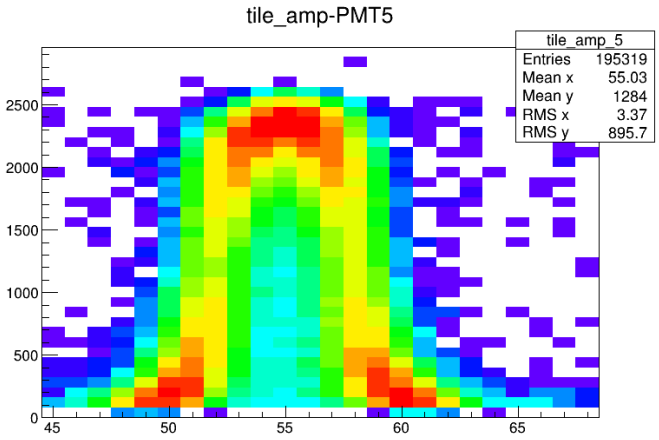
- Tremendous progress has been made in the formulation and production of SciGlass that improves properties and solves the issue of macro defects.
- Scintilex has demonstrated a successful scaleup method and can now reliably produce glass samples of sizes up to ~10 radiation lengths.
- R&D needed: demonstrate scale up to block sizes ≥15 X0. Investigate the consistency of product quality over many repetitions of bar production

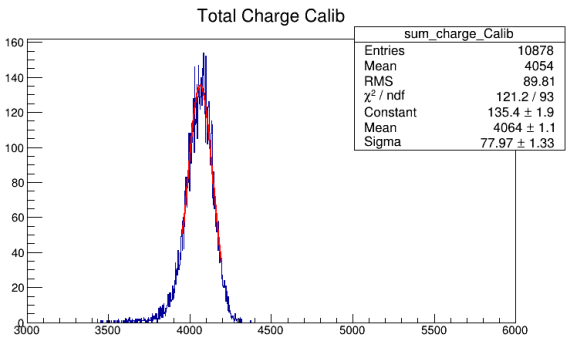
Prototype tests - status



- ✓ ❑ Instrument two 3x3 SiPM and PMT based prototypes to test scintillator materials and test/optimize the entire readout: preamps, fADC and streaming DAQ system
- ✓ ❑ Establish baseline performance with PMT based PWO prototype and standard RO – performed a few test runs
- X ❑ Tests in Hall D with 8 production configurations

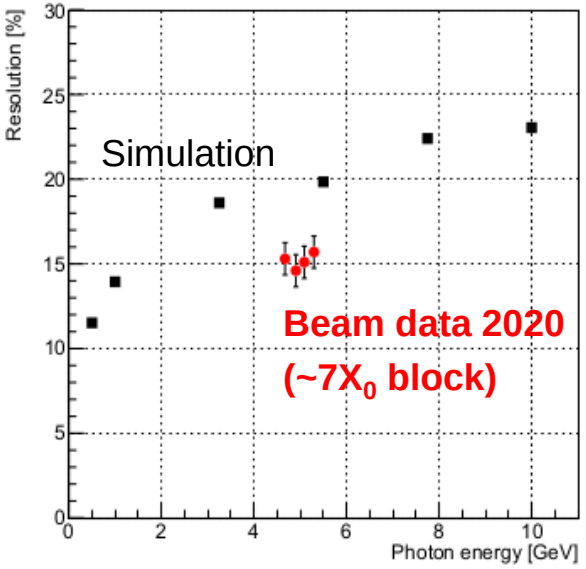
Covid-19 closures of labs and universities



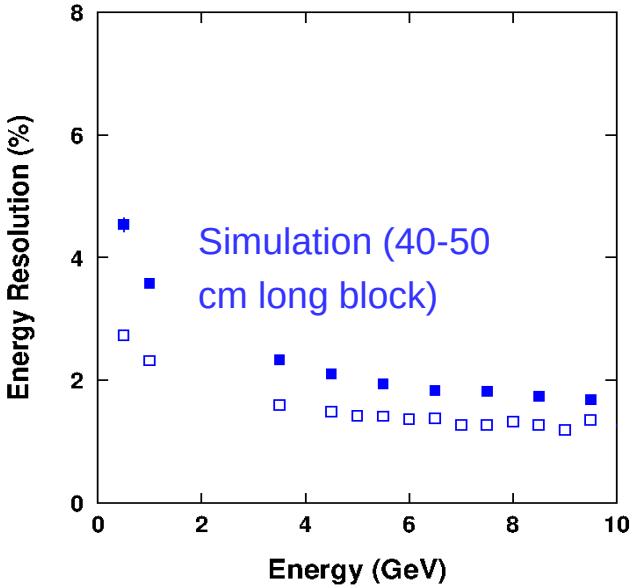


Energy resolution ~1.9% for ~4GeV lepton

SciGlass – Prototype tests



- Test with 2cm x 2cm x 20cm (~$7X_0$) SciGlass blocks: the preliminary results show an energy resolution of ~15% for a 5.2 GeV particle energy.
  - The slightly better performance observed in the experiment is due to the difference in composition/density of the SciGlass and the base composition



- Simulations combined with initial beam tests at photon energies of 4-5 GeV suggest that high resolution competitive with PbWO4 can be reached for ≥15 X0.

- R&D needed: carry out prototype beam test program with to establish SciGlass characteristics

Radiation Hardness – initial tests complete

SCINTILEX

EM irradiation:

- ~1 MeV Co-60
- 160 keV Xray

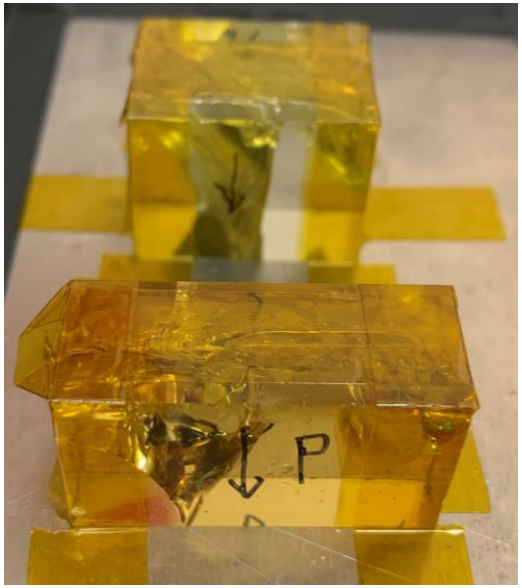
Hadron irradiation:

- 40 MeV protons

Photograph taken immediately after irradiation. No visual evidence of radiation damage (don't get fooled by the yellow Kapton tape)

Before irradiation

After 2min 160KeV Xray at >3k Gy/min



Fluence: 2E15 p/cm^2

Fluence: 1E15 p/cm^2

- G, T, SC, EC series are EM radiation hard
- G, SC series are radiation hard under hadron irradiation

SciGlass Scale-up and production

SCINTILEX

- ✓ Control of process chemistry and material properties
  - glass composition optimization and process modifications to improve uniformity and prevent the formation of bubbles and inclusions
- ✓ Demonstrate basic production processes from a few centimeters up to 2 cm x 2 cm x 20 cm polished bars
- ➡ Extend demonstration of basic production processes up to (2-4) cm x (2-4) cm x 40 cm polished bars (~20 X_0) – first block produced in December 2020 ✓

Essential: SBIR/STTR Phase 2 (submitted proposal for 2021/22)

- Investigate the consistency of product quality over many repetitions of bar production in order to assess the statistical distributions of key properties
- Identify and understand the process parameters that affect these distributions and develop and implement process controls to ensure that the variations of these properties remain within acceptable ranges
- Selection and optimization of process features that are best suited to the projected production rates that are likely to be required

➢ **SciGlass STTR Phase 2 was submitted – CSGlass STTR Phase 1 was awarded!**

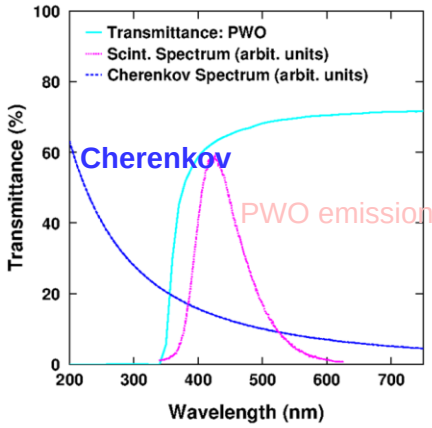
SciGlass development timeline estimate

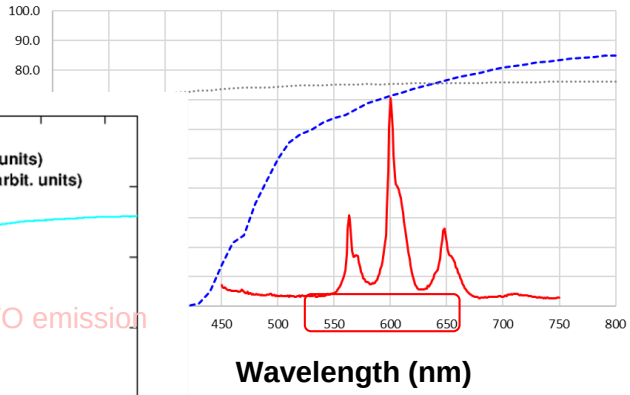
The approximate timeline for completing the SciGlass R&D is about one year assuming R&D funds are available. The goal is to be ready for a day-1 detector. SciGlass could also be available for future detector upgrades.
The estimated cost is $66.5k, which was approved in July 2020, but the funds have not yet been received.

Item	Task	FY20				FY21				FY22				FY23		
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Fabrication	Composition optimization															
	Characterization															
	Scale up and demo 4x4x40cm^3															
	Show uniformity and reproducibility															
	Fabrication process optimization															
	Performance tests with prototype															
	Process design verification to scale up															
	Large scale production study															
Simulations	Prototype															
	Design options															
	Cost/performance optimization															
Prototype	Base version															
	Initial commissioning															
	Upgrade and commissioning															
Beam test	Beam test															
	Data analysis															

CherenkovScintillation (CS) Glass

- CSGlass could be of interest for precision hadron calorimetry with dual readout, where Cherenkov and Scintillation light are detected in the same detector
- CSGlass is derived from SciGlass and expected to be similarly resistant to EM and hadron irradiation up to 100 Gy and 1015 n/cm2



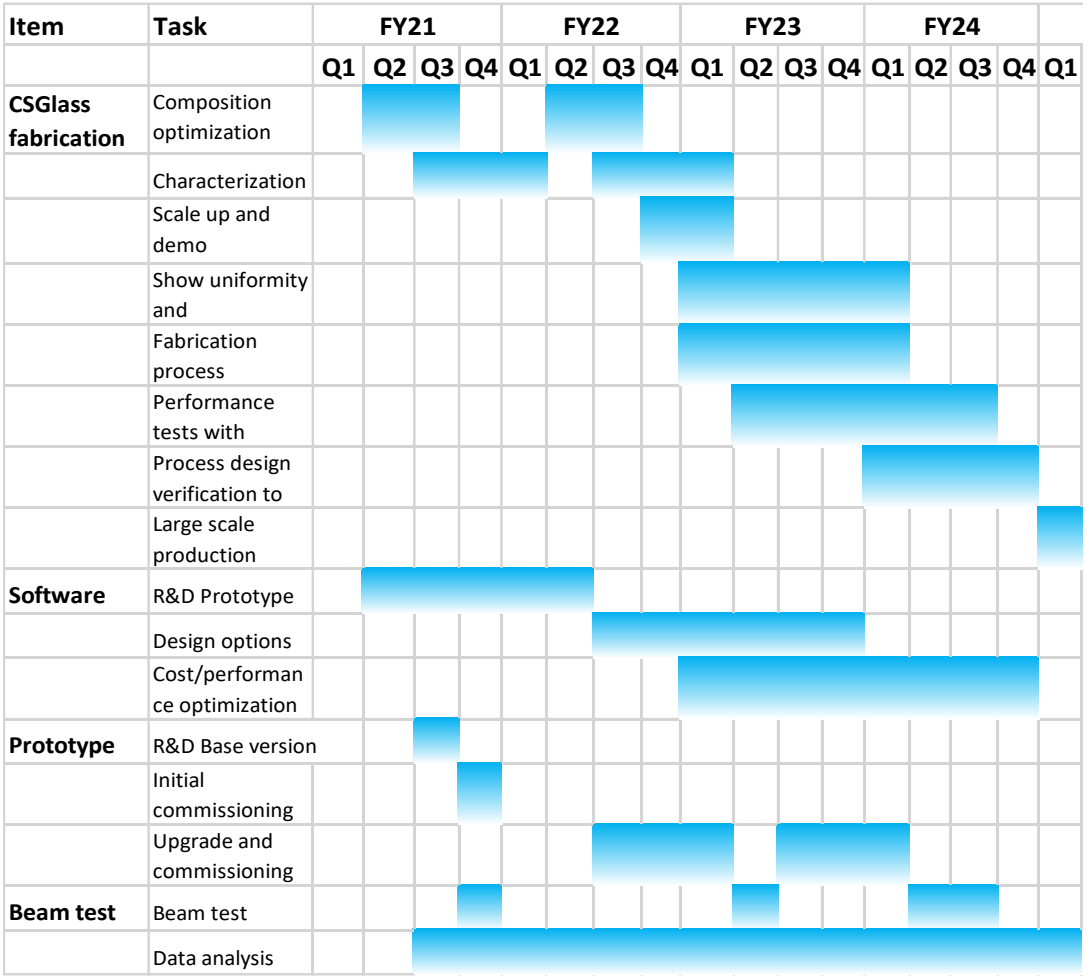


- R&D needed: demonstration of CSGlass with sufficient UV transparency for Cherenkov light collection, clear separation of Cherenkov and Scintillation light of sufficient intensity (slow scintillation, > 500 nm beneficial), low cost, and characterization of CSGlass in the lab and with test beam R&D prototypes.

Very high-density compared to nominal, emits at >550nm, good LY

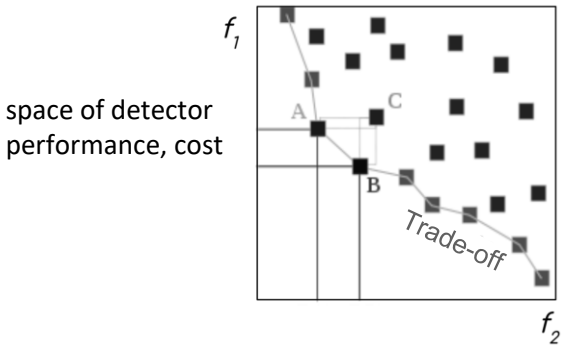
CSGlass development timeline estimate

The approximate timeline for completing the CSGlass R&D is around three years assuming R&D funds are available. CSGlass could be ready for future detector upgrades. The estimated cost for this R&D is $60k/year for three years.



Other activities: simulations to further optimize material & configuration

- GEANT4 simulation including geometry, readout digitization, and reconstruction algorithms
- Analysis plugins for studies of the EEEMCal performance
- Artificial Intelligence Framework to optimize crystal/glass material selection in the shared rapidity region



Conclusion and outlook

- The anticipated technology for the EM calorimeter of the electron endcap (PWO+SciGlass) is mature and will be ready for day 1

  Remaining tasks: SciGlass scale-up and scale production
  Beam tests with prototypes

- CSGlass for hadron calorimetry still requires some R&D (about 3 years, with and estimated cost of $60k/year)

  This could be available for future EIC detector upgrades

Long-term goal:

- Our collaboration would like to construct the electron endcap EM calorimeter (PWO/SciGlass)
- An Expression of Interest (EEEMCal) was submitted by *CUA, FIU, MIT, U. of Kentucky, Lehigh U, Chalres U./Prague* & international institutions *IJCLab-Orsay, AANL-Armenia*